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Book of Abstracts
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Kellie Ann Beall, Editor

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FIRE WHIRL SIMULATIONS

Francine Battaglia, Kevin B. McGrattan, Ronald G. Rehm and Howard R. Baum
National Institute of Standards and Technology
Building and Fire Research Laboratory
Gaithersburg, MD 20899

Abstract

Fire whirls are a rare but potentially catastrophic form of fire. In order for one to exist, there must be an external source of organized angular momentum that produces large swirl velocity components as air is entrained into the fire plume [1]. The vertical acceleration induced by the buoyancy generates strain fields which stretch out the flames as they wrap around the nominal plume centerline. Fire whirls are known to increase substantially the danger of naturally occurring or post-disaster fires [2].

A numerical investigation of swirling fire plumes has been undertaken to understand how swirl alters the plume dynamics and combustion. In a buoyant plume, heated gases rise and entrain ambient fluid from the environment. If vorticity is present in the ambient fluid, it is entrained and concentrated by the plume. This concentration changes the dynamics of the buoyant plume including the entrainment and mixing which control the combustion.

The equations are those that govern three-dimensional, transient, buoyant flow of a thermally expandable ideal gas [3]. The fire is prescribed as a heat source consistent with a mixture-fraction approach to combustion [4]. As in the experiments of Emmons, a circulation is imposed on the fire plume at a prescribed radial distance from the nominal centerline. Three dimensionless parameters govern the flow generated by this model: 1.) the heat-release rate made dimensionless using the thermal characteristics of the ideal gas, 2.) the circulation made dimensionless using the length scale and buoyant velocity based on the heat-release rate [5], and 3.) a Reynolds number for the flow. The experiments of Emmons and Ying measured fire-whirl temperature, radius and height for different imposed values of circulation. The second of these dimensionless parameters is analogous to the reciprocal of the Rossby Number defined in the model of Emmons and Ying to interpret their experimental results.

Large eddy simulation (LES) methodology developed earlier by the authors has been applied [6]. A Poisson equation for pressure is solved using fast direct methods, and a second order explicit Runge-Kutta scheme is used to advance the velocity and temperature fields. This model and computational methodology, using the dimensionless scaling noted above, have been found to reproduce very well mean temperature and buoyant velocity correlations for large fire plumes in the absence of circulation [5,6]

Numerical results show that the structure of the fire plume is significantly altered when swirl is imparted to the ambient fluid. The whirling fire is found to constrict radially and stretch the plume vertically which, in turn, reduces the entrainment of ambient fluid. Consequently, the plume is at higher temperatures over a larger volume and the heat release rate increases throughout the plume. Figures 1a–1b show instantaneous views of the temperature field in a non-swirling fire plume and a whirling fire plume, respectively. The plume temperatures decrease both axially and radially away from the nominal centerline. In Fig. 1b, the

height of the visible flame marked by the dark gray region from the base to about $z = 0.06$ m, increases for the swirling fire and the plume is found to have higher temperatures over a larger region. The overall plume structure of the fire whirl tends to stretch upward and constrict radially, i.e., at $z = 0.20$ m, and appears conical in shape as seen Fig. 1b. In contrast, the fire plume of Fig. 1a does not appear to constrict radially with height and the centerline temperatures are lower near the base. Additional numerical simulations are underway to understand and quantify the dynamics of the swirling fire plume. Results of these simulations will be reported and interpreted in terms of angular momentum conservation under stretching by the buoyant flow induced by the fire. The effects of the circulation on the entrainment and combustion are of particular interest.

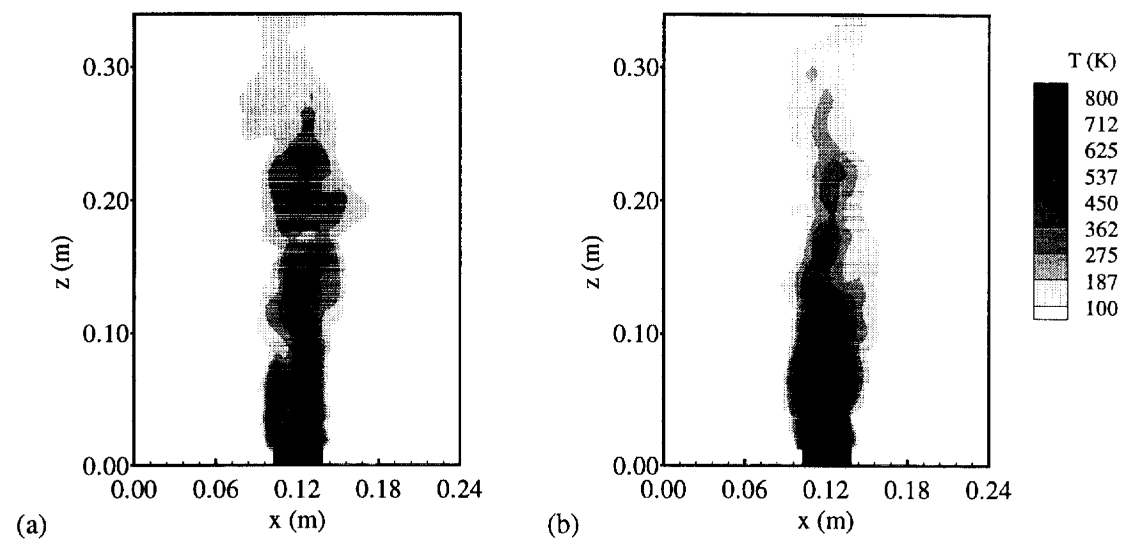

Figure 1: Temperature field in the plume centerplane for a.) a non-swirling fire, and b.) a whirling fire.

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